

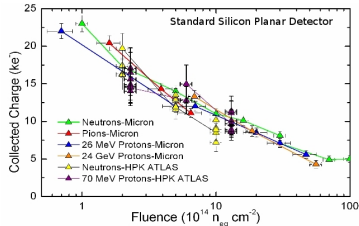
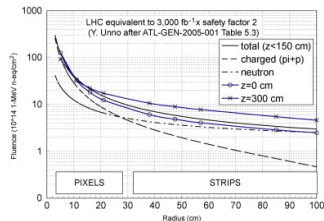
# T-992: Rad Hard Sensors for the SLHC

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for the T-992 Collaboration

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**SLHC:** Luminosity upgraded to  $10^{35} \text{cm}^{-2} \text{s}^{-1}$

- Integrated luminosity up to  $2500 \text{fb}^{-1}$  after 5 years
- at 5 cm from the interaction point radiation fluence of  $10^{16} n_{eq}/\text{cm}^2$ 
  - High radiation damage
  - Less charge collection
  - Less efficiency



**Excellent radiation hardness required**

The aim is to study and compare unirradiated and irradiated detectors to check their performance.

Two types tested:

- ▷ 3D Silicon sensors
- ▷ Diamond sensors

T-992 is a test beam experiment at the Fermilab Test Beam Facility conceived to perform this analysis.

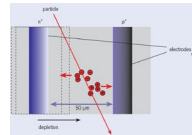
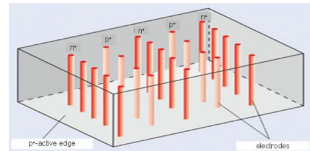
- ↪ 120 GeV proton beam
- ↪ 8 planes pixel telescope to reconstruct particles tracks
- ↪ Several detectors, both irradiated (up to  $10^{15} n_{eq}$ ) and not, available for testing

Several institution collaborated:

<b>Fermilab</b>	S. Kwan, A. Prosser, L. Uplegger, R. Rivera, J. Chramowicz, C. Lei
<b>Purdue</b>	G. Bolla, D. Bortoletto, M. Jones M. Bubna, A. Krzywda, K. Arndt
<b>Colorado</b>	S. Wagner, J. Cumalat, M. Krohn
<b>Texas A&amp;M</b>	I. Osipenkov
<b>INFN Milano</b>	L. Moroni, D. Menasce, M. Dinardo L. Vigani
<b>INFN Torino</b>	M. Obertino, A. Solano
<b>Buffalo</b>	A. Kumar, A. Godshalk
<b>IHPC Strasbourg</b>	J. M. Brom
<b>Mississippi</b>	L. Perera

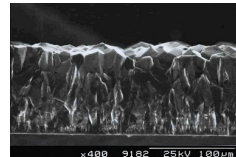
**3D** Electrodes inserted in the silicon bulk:  
charge collected laterally along a shorter  
path

- ✓ Lower depletion voltage
- ✓ Faster charge collection
- ✓ Less carriers trapping
- ✗ Higher capacitance → higher noise

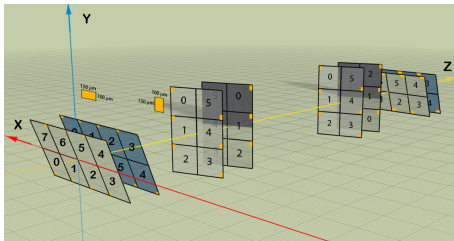


**Diamond** Planar sensor with an intrinsic high  
radiation hardness: high bandgap

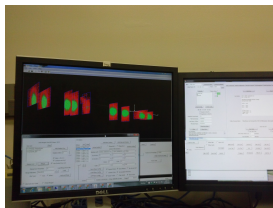
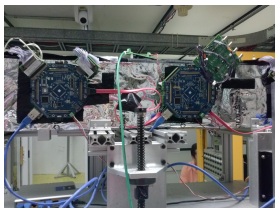
- ✓ Faster charge collection
- ✓ No leakage current
- ✗ Less charge carriers produced → lower signal
- ✗ Trapping due to imperfections in crystalline structure



8 planes of pixel detectors, 4 upstream and 4 downstream, with the DUTs in the middle.



- $100 \times 150 \mu\text{m}^2$  pixels
- Track reconstruction and plane alignment algorithm
- Effective resolution  $\simeq 6 \mu\text{m}$



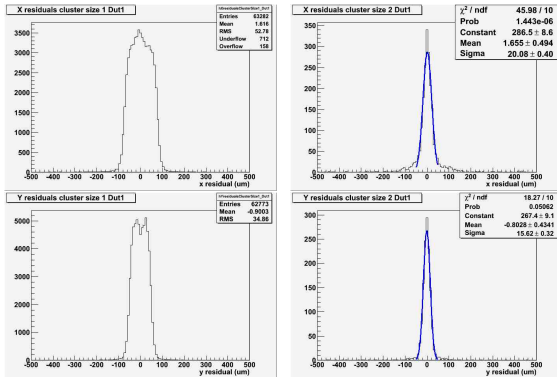
The telescope and its data software: after each run it was possible to verify the quality of the data

# Analysis

Many detectors have been analyzed to obtain a large variety of results:

- ★ Various scans to run in different conditions
  - ✓ Bias scan
  - ✓ Threshold scan
  - ✓ Angle scan
- ★ Various types of analysis pursued:
  - ✓ Resolution
  - ✓ Efficiency
  - ✓ Charge collection
- \* Data were taken in the last two weeks of September
- \* In the next slides are shown some preliminary results already available for an unirradiated and irradiated ( $1 \cdot 10^{15}$  neq/cm<sup>2</sup>) 3D, and an irradiated ( $3.5 \cdot 10^{14}$  protons/cm<sup>2</sup>) Diamond pixel.

## 3D Residuals

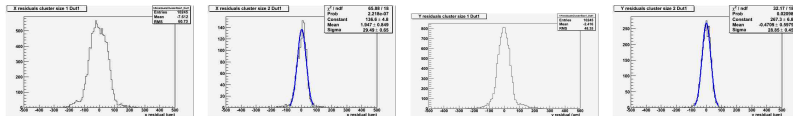


X residuals for size 1 and 2 clusters

Y residuals for size 1 and 2 clusters

Size 2 clusters are still computed as for planar detectors: a new method must be pursued to improve their resolution!

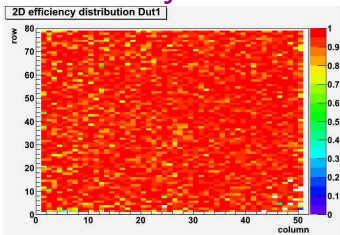
## Diamond Residuals



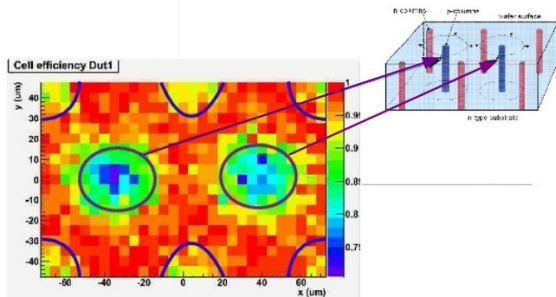
Same plots



## 3D Efficiency

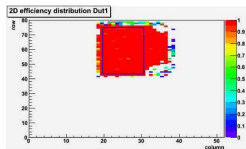


Efficiency spatial distribution on detector: mean efficiency = 94.3% (unirradiated)

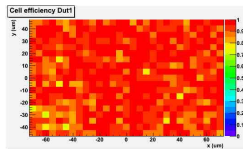


Distribution on cell: note the electrodes!

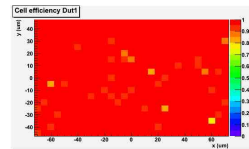
## Diamond Efficiency



Efficiency spatial distribution on detector: mean efficiency = 94% (irradiated)

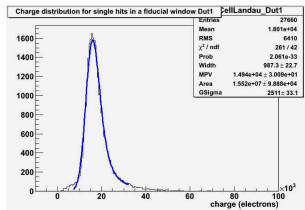


Distribution on cell: bad values due to bad working pixels, the readout chip was damaged by irradiation.

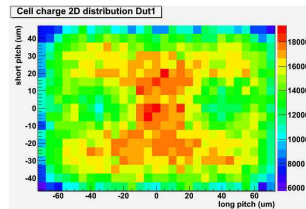


Distribution on cell if we focus on the center of the detector (blue rectangle): mean efficiency = 99.4%

## 3D Charge Distributions

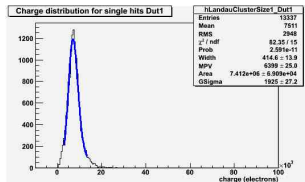


Charge overall distribution (Landau):  
M.P.V. =  $14.9 \cdot 10^3 \text{ e}^-$

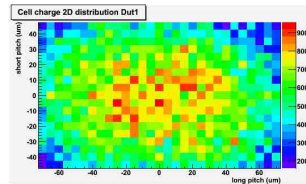


Average charge spatial distribution on cell

## Diamond Charge Distributions

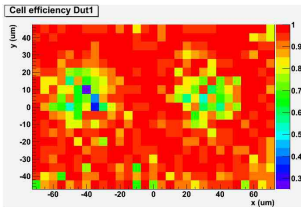


Charge overall distribution (Landau):  
M.P.V. =  $6.4 \cdot 10^3 \text{ e}^-$  (irradiated!)



Average charge spatial distribution on cell

## Efficiency

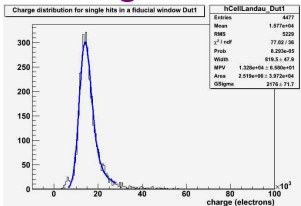


Efficiency on cell: average efficiency = 93.2%

→ Slightly lower than the unirradiated, as expected!

Alignment not perfect → Must be improved!

## Charge collection



Overall charge distribution (Landau):  
M.P.V. =  $13.3 \cdot 10^3 \text{ e}^-$

→ Slightly lower than the unirradiated, as expected!

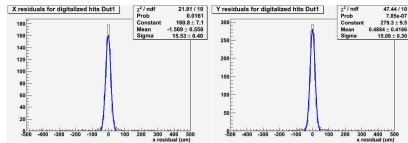
Still working well after a dose of  $1 \cdot 10^{15} \text{ neq/cm}^2$

- ✓ Several detectors successfully tested
- ✓ Preliminary results in agreement with predictions so far:
  - Comparison between not irradiated and irradiated sensors
  - Resolution and Charge collection parameters

## Work in progress

- ▷ Improve the analysis to understand behaviour at the boundaries between the pixels and at the edges of the detectors
- ▷ Improve the size 2 clusters reconstruction

→ See for example size 2 residuals when the point is "digitalized" (set at the boundary of the pixel) and the charge is set to be below  $20 \text{ ke}^-$  (to cut  $\delta$  rays off)



- ▷ Analyze the data at angles  $> 0^\circ$

## Future Goals

- ▷ Study detectors irradiated at higher doses